THE FORMATION OF CAPE COD.

BY WARREN UPHAM.

[*Continued from August Number.*]

ON Cape Cod, as on Long Island, Martha's Vineyard and Nantucket, we find, south of the line of morainic hills, an area of modified drift in extensive plains which slope very gently southward. These are fully ten miles wide from north to south in Sandwich, Falmouth and Mashpee, and thence to the east they have an average width of five miles. From the south-west limit of this area at Falmouth village, the traveler who follows the road along the south side of the cape through Waquoit, Cotuit, Hyannis and the south villages of Yarmouth, Dennis and Harwich, sees only level plains twenty-five to forty feet above the sea, with occasional hollows and valleys, most of which are occupied by ponds and brooks. No boulders are seen in this distance of more than thirty miles. They occur, however, in the small hills west of Hyannis harbor, the highest of which is eighty-one feet above the sea, and in lower mounds and ridges two and a half miles south-east at Point Gammon. Shoals of boulders, known as Collier's Ledge and the Bishop and Clerks, lie three miles off shore opposite to these points. Chatham and Orleans, at the east end of this area, are also modified drift, but its surface is very irregularly moulded into hills, ridges and enclosed hollows, the highest elevations being about one hundred and twenty-five feet above the sea. The north edge of this area, next to the terminal moraine, consists of more elevated plateaus, fifty or seventy-five to two-hundred feet in height. From this line there is a continuous slope southward, scarcely perceptible but declining in the five to ten miles of its extent to within twenty-five to forty feet above the sea. This north portion of the plains is marked by frequent hollows of large extent, which contain ponds fifty to one hundred feet below the general surface.

A fine idea of the slope of this deposit of modified drift is obtained in a journey from Sandwich to Greenville, Ashunet pond and Falmouth. The ascent of two hundred feet or more from sea-level to the highest point of the road is accomplished in two miles, bringing us to a point on the road where Bourne's hill, the highest on Cape Cod, is within a half mile to the east, while close at the west is the Great Hollow, about one hundred feet deep and

perhaps a half mile wide, and twice as long from north to south. This is enclosed on all sides by the hills and high plains, but contains no water, showing that the plane of saturation is very deep; while copious springs at the north foot of the hills indicate that it falls in that direction. Without descending more than twenty feet below its highest point, the road next enters upon a plain of gravel and sand, and thence extends seven miles before crossing the first hollow, which is at Ashunet pond. Beyond this point it crosses numerous depressions, that are or have been water courses; but there is no break in the continuity of the plains, which in about twelve miles descend by a gradual slope from the height of two hundred feet to sea-level.

These plains of Cape Cod are further like those of Long Island, Martha's Vineyard and Nantucket in being indented by narrow arms of the sea, which reach one to two miles inland, filling the lower end of long depressions that continue across the plains to the north, being either dry or occupied by small streams.[1] The plains and valleys which thus generally border the terminal moraines on their south side appear to have been formed by the same floods which deposited the large amounts of modified drift along the edge of the ice-sheet. Much of their finer gravel and sand was carried forward by the descending currents, and spread in these gently sloping plains, while the valleys of drainage seem to have been made by the same waters at their lower stages.

The continuation of these valleys below our present sea-level calls up one of the most complex but at the same time most important and interesting questions connected with glacial geology. This feature shows plainly that when these valleys were formed the sea did not reach so high upon the land as now; and if we extend our inquiries we find that everywhere around the world the glacial period was marked by most extraordinary changes in the relative heights of land and sea. These remarkable oscillations, which had one extreme at the equator and the other at the poles, appear to have been changes in the level of the ocean. It seems not unlikely that an eighth part of the earth's surface had become covered with ice, and if we consider a slope of one-half a degree to be needed to give it motion, an estimate of four miles for its average depth does not seem to be too great.

[1] These valleys on Long Island have been described by Mr. Elias Lewis, Jr., in *American Journal of Science and Arts*, 3d series, Vol. XIII, pp. 142–146 an 215.

The removal of the water thus taken from the sea and stored up in accumulations of ice would lower the surface of the ocean more than a half mile. At the same time this vast accumulation of ice in high latitudes must draw the sea by gravitation away from the equator toward the poles. This cause appears to have retained the sea-level at about its present height near the lower limit of the ice-sheet, while in arctic regions it rose much higher than now. Marine shells in the modified drift show that the sea thus stood fifty to two hundred feet above its present height on the coast of New Hampshire and Maine; five hundred feet in the valley of the St. Lawrence, and one thousand to two thousand feet higher than now along the west coast of Greenland. Everywhere in high latitudes, both in the northern and southern hemispheres, we have proof of such a submergence of the land when the drift was accumulated, increasing in amount the nearer we go to the poles. On the other hand, the coral islands of the tropics are witnesses of the depression of the sea in this period, amounting to three thousand feet, or perhaps more, at the equator, while different evidence shows that at the mouths of the Mississippi, Ganges and Po rivers it was at least four hundred feet lower than now. If we reflect upon these widespread changes of sea-level that marked the glacial period, occurring only where they would be produced by taking water from the sea to form ice-sheets and by gravitation through their influence, and if we compare these recent simultaneous changes with the general stability of the continents, we seem compelled to attribute them to movements of the sea rather than of the land.

Because of the attraction of accumulations of ice that still remain about the poles, where probably little or none existed in Tertiary times and at the epoch immediately preceding the glacial period, the sea along the eastern coast of the United States appears to be lower now than during those periods, uncovering the Tertiary border of the Southern States and leaving pre-glacial deposits with marine shells, apparently Post-pliocene, fifty to two hundred feet above our present sea-level, under the terminal moraine and modified drift of Long Island. The entirely unstratified character which marks many portions of the terminal deposits of the ice-sheet, reaching quite to the sea-shore, and the still lower extension of the channels which appear to have been cut by the floods formed at its melting, indicate that at the south

coast of New England the sea was depressed in the glacial period below its present height. The submarine channel of Hudson river shows that after this time it sank five or six hundred feet lower than now, apparently because the south part of the glacial sheet had been melted, greatly diminishing its attractive force at this latitude. With the more complete departure of the ice the sea-level has been restored to approximately the same condition as before the glacial period, being still rising on the eastern coast of the United States at the rate of about a foot, or less, in a hundred years.

The channels which we have described as occurring on the plains that slope southward from the series of hills, are best shown on Cape Cod, in Falmouth and eastward to Cotuit harbor, which is the region directly south from the angle of the terminal moraine and from its highest hills, which in this portion of its course are composed mainly of modified drift; in other words, they occur most abundantly where the drainage from the melting ice-sheet must have been greatest, including all the floods poured down from the ice-fields along the line between Falmouth village and North Sandwich, those that converged toward the angle of the ice-margin, and those which brought down its vast frontal hills of gravel and sand along several miles eastward. Some of the hollows containing ponds, which are found frequently on these plains, may have been left unfilled because masses of ice remained there while gravel and sand were rapidly deposited about them; but probably in most cases they are due to unequal deposition, though with unobstructed drainage.

North and north-north-west from the angle of the moraine, a most irregular belt of kame-like modified drift in ridges, hills, plateaus and hollows of every shape, but generally with a north-to-south trend, reaches to Kingston, a distance of nearly twenty miles. These deposits are finely seen along the road from North Sandwich by Great and Little Herring, Bloody and Long ponds. The elevations are fifty to one hundred feet above the depressions, and one hundred to two hundred feet above the sea. The material is obliquely bedded sand and coarse gravel, with pebbles up to one foot in diameter. Boulders are rare or entirely wanting for some eight miles, till we reach Pine and Manomet hills, already described, which seem to constitute a medial moraine of coarsely rocky unmodified drift, accumulated by ice-currents without the agency

of running water. The descending slopes and consequently the currents of the ice on the east and on the west appear to have met here; and when the period of melting came, it was along this belt, extending from North Sandwich to Kingston, that the largest and most heavily loaded rivers flowed down from the departing ice-fields. A great part of their deposits of gravel and sand appear to have been laid down in channels and upon open areas which still remained walled by ice, but when this disappeared they remained in kames or ridges, hills and plateaus, with many enclosed hollows. Telegraph hill, about two hundred and seventy-five feet in height above the sea, and others seventy-five to one hundred feet lower, lying within two or three miles west from the south end of the Pine hills, are probably mostly modified drift, though overspread with frequent boulders up to ten feet in diameter. These are short parallel ridges, with a north-to-south trend, separated by hollows fifty to seventy-five feet below the crests. About Plymouth village the modified drift forms kame-like hillocks and small plains, which are separated by very irregular hollows and valleys. The tops of these deposits have a nearly uniform height, which varies from one hundred to one hundred and twenty-five feet above the sea. Two miles to the west is an irregular series of hills, resembling a terminal moraine, which reaches some three miles westward, varying in height from one hundred and seventy-five or two hundred feet to three hundred and thirteen feet at Monk's hill, in Kingston. Most of these appear to be unstratified boulder-drift, but the top and north side of Monk's hill are waterworn gravel and sand with only few boulders.

In the west part of Plymouth level plateaus and plains of modified drift prevail, broken by frequent hollows of small area with steep sides, containing ponds. These are so numerous that this township is said to have a pond for each day in the year. To the west and north the greater part of Plymouth county consists of similar nearly level or moderately undulating deposits of modified drift fifty to one hundred and fifty feet above the sea. These beds of sand and gravel cover the townships of Wareham, Carver, Middleborough, Plympton, Halifax, Duxbury, Pembroke, Hanson, Hanover, the west part of South Scituate and much of Hingham, reaching continuously from the angle of the terminal moraine of Cape Cod more than thirty-five miles north-north-westward to the

south shore of Massachusetts bay. None of the streams of this region can be supposed to have aided in the accumulation of these materials, instead of which they are evidently carrying away small portions as they gradually deepen and extend their channels. The origin of these plains seems to be due, like the kames of Plymouth, to floods and detritus supplied by the melting ice-sheet which sloped from both sides toward this area. The deposits made in the lower part of the channels of these glacial rivers, between walls of ice, remain as kames, or ridges and hills, composed mainly of coarse gravel, while the portion carried forward and spread beyond the retreating ice-margin forms the nearly level plains.

The only fossils found upon this area are within about a mile south-west from South Marshfield, and were encountered many years ago in digging wells at the houses of Messrs. Kent, Chandler, Wadsworth and Sprague, which succeed each other along a distance of one-third of a mile, the last being in the edge of Duxbury. All these wells showed a surface of modified drift ten to twenty feet deep, enclosing occasional boulders, underlain by a hard ferruginous stratum, six inches to a foot thick, below which were muddy silt, sand and fine gravel, containing successive fossiliferous layers, those at Mr. Chandler's well being four in number, twenty to thirty-five feet below the surface, at heights twenty-five to forty feet above the sea. The fossils include casts of the quohog, long and razor clams (*Venus mercenaria*, *Mya arenaria* and *Ensatella americana*), and numerous fragments of lignite. The iron-rusted stratum, varying in height from thirty to fifty feet above the sea, and extending continuously at least a third of a mile, seems to represent the depth to which the preglacial deposits were eroded by the ice-sheet, and the lower beds were probably contemporaneous with those at the base of Sankaty Head.

The extreme portion of Cape Cod, north from Orleans to High Head, consists entirely of modified drift. Boulders are very rare, but in two places seem worthy of notice; one of these is about a mile south-west from Nausett Lights, in Eastham, where an enormous boulder, called Enoch's or Great Rock, lies apparently half buried in the sand. The portion in sight is thirty-three feet long, twenty-five feet wide and fifteen feet high. Only two or three other boulders were seen here, none of them exceed-

ing five feet in diameter. The other locality is about a sixth of a mile west from Highland Light, where one block fifteen feet long and several others five feet long occur. In the north part of Eastham the modified drift forms extensive level plains about fifty feet above the sea. From South Wellfleet to High Head, in the north part of Truro, the contour on the west side of the cape is in very irregular small plateaus, ridges and hills, nearly uniform in their height, which varies from one hundred to one hundred and fifty feet above the sea, increasing from south to north. These enclose depressions from twenty to one hundred feet deep, many of which contain ponds. They are also intersected from east to west by broad valleys with steep sides, which have their bottom nearly at sea-level or below it. Examples of these are the hollow which extends from North Truro toward Highland Light, and that of Pamet river, which varies from a third of a mile to one mile in width, and cuts the cape quite across, its bottom, until recently dyked, being marsh overflowed by high tides.

The east side of the cape, through Wellfleet and Truro, is a nearly continuous bluff, one hundred to one hundred and sixty feet high, horizontally stratified, being evidently a remnant of a nearly level plain, the east part of which has been washed away by the sea. This process is still going forward, exposing fine sections of these deposits along most of this distance. The material is mainly sand and fine gravel, with coarse gravel in some portions, containing pebbles and fragments up to one foot or rarely two feet in diameter. Less than a half dozen larger blocks, none of them, however, so large as four feet through, were seen in this whole line of cliffs more than fifteen miles in extent. At the base of these bluffs banks of darkish sandy clay occur in several places, rising ten to forty feet above the shore and extending one hundred to five hundred feet in length. These beds enclose occasional pebbles up to one foot in diameter. At the Clay Pounds, close north of Highland Light, is a massive bed of somewhat similar sandy clay, bluish-gray in color, forty to fifty feet thick, extending a quarter of a mile to the west, as shown by wells, and the same distance along the cliffs to the north, where it gradually thins out. This deposit is finely laminated, level in stratification and free from pebbles. Its base is clearly seen in many places for an eighth of a mile holding a nearly constant height of forty feet above sea-level, and is marked by a hard fer-

ruginous layer one to three inches thick. It rests, by abrupt change, upon gravelly sand containing pebbles up to one inch through, and within ten feet below they occur up to six or eight inches in diameter. The thickest portion of the clay is at the south edge of a gully some thirty rods north of the lighthouse, where the section is gravelly sand to forty feet above the sea; clay fifty feet thick, and sand at top twenty-five feet. The upper part of the clay here and generally, is more sandy than its base, but it is still quite distinctly separated from the overlying sand. A quarter of a mile north the clay becomes narrower, and its base is higher, the section being sand and gravel to sixty-five feet above the sea, clay ten feet, and sand at top fifteen feet. Heights along this portion of the cape are as follows: in Eastham, fifty to seventy-five feet; Lombard's Head, in Wellfleet, about one hundred and twenty-five; highest portion of bluff in south part of Truro, one mile south of Pamet river, about one hundred and fifty; Small's hill, one mile north-east from Truro village, highest point beyond Barnstable on the cape, about one hundred and seventy-five; bluff one mile south of Highland Light, one hundred and sixty; base and focal plane of this lighthouse, one hundred and thirty and one hundred and eighty-five; High Head, about seventy-five.

As in Plymouth county the accumulation of these thick and extensive beds of modified drift, remote from any large river and here bordered on each side by the sea, seems capable of explanation only by supposing the material to have been held in the ice-sheet and deposited by the floods produced at its retreat. When the return of a warmer climate drove back the front of these ice-fields from their terminal moraine upon Cape Cod, the rivers which flowed down from their melting surface were discharged upon these areas, those at the south-west converging upon Plymouth county, while those which descended from the glacial sheet over the west part of the Gulf of Maine had their mouth in Wellfleet and Truro.

The only fossils that have been found on Cape Cod occur in the bluffs on the east shore of Truro, as follows: One mile south from the head of Pamet river the section shows gray sandy clay at base to about thirty feet above the sea; ferruginous gravel, containing broken and worn shells, and with its largest pebbles four inches through, five feet; overlain by more than one hun-

dred feet of sand with occasional gravelly layers. Four to eight rods farther south the clay rises ten feet higher, but at four hundred feet south and at one hundred feet north its top is only twenty feet above the sea. The bed of shelly gravel thins out at three or four rods on each side. Species found here are a *Balanus*, *Neptunea pygmæa* Adams, *Tritia trivittata* Adams, *Lunatia heros* Adams, *Turritella erosa* Couthouy, a *Mya* hinge, *Ceronia deaurata* Gould, *Mactra solidissima* Chem., *Cardium islandicum* L., *Cyclocardia borealis* Conrad, *Astarte undata* Gould, and *Pecten islandicus* Chem. A peaty or lignitic layer, about a half inch thick and extending five feet, was noticed at one place in white sand, three inches above this shelly gravel. A third of a mile north from the head of Pamet river, the bank is about one hundred and twenty-five feet high, consisting of sand with occasional thin layers of gravel, and containing fragments of shells to a height at least sixty feet above the sea. Among these *Ceronia deaurata* and *Pecten islandicus* were recognized. About a mile and a half farther north, or one mile south from Highland Light, the bluffs reach their greatest height, and here worn shell fragments were again found at two localities, a third of a mile apart, occurring in gravelly sand from near sea-level to at least one hundred feet above it. These include *Balanus* species, *Neptunea pygmæa*, *Aporrhais occidentalis* Sowerby, *Acmæa testudinalis* Forbes and Hanley, *Ceronia deaurata*, *Cardium islandicum*, *Cyclocardia borealis*, *Astarte undata* and *A. castanea* Say, *Pecten islandicus* and an *Anomia*. Lignite was observed at the most northern of these localities thirty to forty feet above the sea, in several layers an inch or less in thickness and at least four or five feet in extent. At about the same height the sand and fine gravel here contains clay boulders[1] or pieces of dark sandy clay of irregular shape, and varying in size from three or four inches to two feet long. These are changed to a brown color for a depth of a half inch from the outside, due to oxidation of their iron.

We have already seen that the unstratified character of portions of the terminal moraines, and the channels upon the plains that lie south of them, indicate that in this latitude, during the period when these beds were deposited, the sea stood somewhat

[1] Also found in the modified drift of Long Island, as described by Mr. Elias Lewis, Jr., in *Popular Science Monthly*, Vol. II, p. 634, and in North-western Ohio, according to Prof. N. H. Winchell, *ibid*, Vol. III, p. 202.

lower than now. The occurrence of these recent marine shells up to one hundred feet above the sea, would disprove this conclusion if they lay in an undisturbed condition so as to show that they lived where they now are found; instead of this, they are always more or less broken and worn, no two corresponding valves being found together; and their origin, as well as that of the lignite, clay boulders, and the much older fossiliferous pebbles, next to be described, seems to have been from pre-glacial beds which were formed on the floor of Massachusetts bay. These appear to have been eroded by the ice-sheet, lifted into its mass, and at its melting deposited anew by the glacial rivers, their marine shells being thus embedded in modified drift which was accumulated above the sea-level.[1] The species are of northern range, such as would have been found living in the ocean when it was invaded by the onflowing ice.

A third of a mile north from the last locality, and one half mile south from Highland Light, the bluff rises to a height of one hundred and fifty feet, and consists of sand and gravel, much coarser than usual, having pebbles of all sizes up to one foot in diameter, mostly rounded by water wearing, but a part of them angular, especially the larger pieces, some of which may be two feet long. The foot of the cliffs here is guarded from the waves by several rods of sea-sand covered by beach grass, so that the gravel and sand have fallen down in a steep slope strown with pebbles. Among these are occasional fragments of a whitish calcareous sandstone, thickly filled with shells, which were brought to my notice by Mr. David F. Loring, keeper of the Highland Light. They occur rarely for twenty or thirty rods along the face of the cliff at all heights up to one hundred and twenty-five feet, being most abundant between seventy-five and one hundred feet above the sea. Like the other pebbles, most of these pieces are more or less water worn, some of them being rounded on all sides, indicating that their mode of transportation and deposition were the same; but the stratification is obscured by falling down, so that we do not here find these fossiliferous pebbles actually embedded in the drift. Before seeing any of these specimens,

[1] Marine shells occurring in the till of Scotland are similarly attributed by Croll, Geikie and others, to erosion by the ice-sheet of previously existing marine beds and their transportation to higher levels, so that they cannot be accepted as proof that the sea stood at the height where they are now found. Geikie's "Great Ice Age," 2d edition, pp. 179–181.

however, I had found a fragment of the same shelly rock in the fossiliferous layer of gravel first described, one mile south from the head of Pamet river; and subsequently I found two other bits of it at the most northern locality of shelly gravel and sand last mentioned. These pieces were enclosed in stratified beds, in each case some thirty feet above the sea, evidently occupying their original position in the thick deposits of modified drift which form this part of Cape Cod. The fossiliferous pebbles are thus shown to have been brought to their present place by the same agencies which accumulated these beds of gravel and sand. As no similar formation is known on the land to the north from which they could be derived, it seems quite certain that they represent beds that were in place at the bottom of Massachusetts bay, whence they were ploughed up by the ice-sheet and carried forward and upward in it, till at its final melting they were deposited here.

The scarcity of these fragments is such, that a search of six or seven hours was required, where the whole bank, one hundred and fifty feet high, was plentifully strown with pebbles, to find a dozen of them. These, to the amount in all of perhaps twenty pounds' weight, were presented to the Boston Society of Natural History, and their fossils have been examined by Mr. W. O. Crosby,[1] who regards them as satisfactory proof that the rock is Eocene Tertiary. The species which he has identified are *Camptonectes calvatus* Conrad, found in the Middle Eocene of South Carolina; *Venericardia planicostata* Lamarck, found in the Lower Eocene of Virginia; probably *V. parva* Lea, found in the Eocene of Alabama; and another similar to the common *V. alticostata* Conrad, occurring with the last; probably *Ostrea divaricata* Lea, of Middle Eocene in Alabama, though perhaps young of *O. sellæformis* Conrad, a characteristic species of the Lower Eocene from that State to Virginia; another, principally in fragments, is similar to the recent *O. virginiana* Lister; another species of this genus is represented by fragments of shell fully one and a half inches thick, not enclosed in the matrix of calacreous sandstone like the rest, but found with these shelly pebbles on the cliff a half mile south of the lighthouse, and also in the shelly gravel south of Pamet river; an *Anomia* similar to *A. tellinoides* Morton, of the Cretaceous in New Jersey, Alabama

[1] Proceedings of Boston Society of Natural History, Vol. xx.

and Mississippi; a *Plicatula* similar to *P. filamentosa* Conrad, and an *Axinea*, closely like *A. staminea* Conrad, both of the Alabama Eocene; also probably *Striarca centenaria* Conrad, found in the Miocene of the Southern States. Other molluscan genera that were recognized are *Corbula*, *Cardium*, two species of *Yoldia* or *Nuculana*, several small *Turritella*-like species, and a small *Natica*. Echinoderms are represented by spines of a *Cidaris*, and cœlenterates by a simple cylindrical *Galaxea*-like coral.

In this connection it is interesting to notice that fragments of fossiliferous rock,[1] apparently of Miocene age, are brought up from the sea-bottom on George's Bank, Banquereau and the Grand Bank, by the coralline growths attached to them becoming entangled with fishermen's lines. These, with the Eocene pebbles of Cape Cod, show that the coast of New England, Nova Scotia and Newfoundland, one thousand miles in extent, is bordered by submerged Tertiary formations similar to those which occur above sea-level in the Southern States, as had been already suggested by Prof. C. H. Hitchcock[2] before these discoveries. It was a theory of Agassiz that the fishing banks, from which these Tertiary rocks are drawn up, represent the terminal deposits of drift accumulated at the front of the ice sheet. Both this and the theory of Prof. Hitchcock appear to be true, for besides the fossiliferous fragments many of granites and schists are also obtained by the fishermen. Furthermore the course of the extreme terminal moraine that crosses New Jersey, Long Island, Block Island, Martha's Vineyard and Nantucket has its line of continuation in these remarkable submarine banks, which probably consist, somewhat like Gay Head, of Tertiary strata covered with their own and foreign detritus brought by the ice-sheet.

The moraine of Cape Cod, the Elizabeth islands, Southern Rhode Island and the north shore of Long Island, was formed after the ice had retreated from its farthest limit, but while it still terminated eastward beyond the present coast line. This halt in its departure was extended along the entire margin of these ice-fields to the west, for a distance of more than two thousand miles. Although in the interior of the United States the extreme limit of glacial action has not yet been found to be generally marked by extraordinary deposits, a most notable series of terminal mo-

[1] Described by Prof. Verrill in *American Journal of Science and Arts*, 3d series, Vol. XVI, p. 323.

[2] *Appalachia*, Vol. I, p. 13, and Geology of New Hampshire, Vol. II, p. 21.

raines north of this line and probably contemporaneous with that of Cape Cod is found, as recently shown by Prof. Chamberlin,[1] stretching across Ohio, and represented in Southern Michigan, in the Kettle moraine of Wisconsin, and the Leaf hills of Minnesota; while its farther continuation seems to be in the Coteau des Prairies and the Coteau de Missouri of Dakota and British America, reaching north-westward, according to Mr. G. M. Dawson,[2] to the North Saskatchewan river, three hundred and fifty miles west of Winnipeg lake. These deposits, like the moraines of Southern New England, are made up entirely of drift materials, partly unstratified, with abundant boulders, and partly stratified gravel and sand, in hills one hundred to three hundred feet high, of very irregular contour, with many enclosed hollows and occupying a width of from one to thirty miles. They lie upon the uneven surface of the rocky strata, being continuous across valleys and ranges of highland, which in Wisconsin undulate eight hundred feet in vertical height, while the elevation of this entire series varies from sea-level at Cape Cod, to two thousand feet above it at the north line of Dakota. In the Western States the front of the ice-sheet is shown by Prof. Chamberlin to have been lobed, producing acute angles in its terminal moraine, with medial moraines extending northward from them; corresponding to which we find a deflection of ninety degrees in this series of hills on Cape Cod at North Sandwich with the massive medial range of Pine and Manomet hills a few miles farther north, in Plymouth. The same lobed character appears also to have marked the ice-sheet at its greatest extent, leaving a large driftless area in Wisconsin, and making angles similar to those of a later period in its frontal line, as indicated by the drift-hills of Martha's Vineyard and Nantucket.

The north end of the modified drift of Cape Cod is at High Head; and the whole of Provincetown, at the extremity of the peninsula, consists of sea sand with no pebbles. This sand has come from the erosion by the sea of the east shore of the cape; has been swept north and west by tidal currents to its present place in the lee of this breakwater; lifted by the waves into beach-ridges and further raised by the wind into hills a hundred feet in

[1] "On the Extent and Significance of the Wisconsin Kettle Moraine," in Transactions of Wisconsin Academy of Science, 1878, with maps.

[2] In *Quarterly Journal of Geological Society*, Vol. XXXI, pp. 614–623, with map.

height. From Nausett Lights to High Head much of the cape, as it originally was, has been demolished, and the process is still going forward; but the sea restores a part of what it takes, forming this curved bank of sand, five miles long and one to three miles wide, which encloses the deep and commodious harbor of Provincetown. The section here, to a depth of one hundred and eighty-two feet, was shown by a boring made some twenty years ago at the end of Central wharf. Sand extended from low tide line for thirty-five feet, below which interstratified sand and fine gravel continued to one hundred and seventy feet, where the first clay was encountered. This was dark-colored and very compact, extending twelve feet, at which depth it was not penetrated. Shells of *Scapharca transversa*, *Ostrea virginiana* (at one hundred and twenty feet), *Lunatia heros* and others were found to the depth of at least one hundred and forty feet. Successive generations of these inhabitants of the sea have been buried during this accumulation of its detritus, and at the same time its waters have probably been gradually rising upon the land.

The height of the principal hills of this town, as determined by Major Graham of the Coast Survey, are as follows: Mt. Ararat, one hundred feet above mean low tide; Mt. Gilboa, one hundred and six; Oak Head, one hundred and four; Miller's hill, eighty-nine; High Pole hill, one hundred; Telegraph hill, ninety-eight; Creek hill, eighty-four. These are dunes on the harbor side which have mostly become covered with bushes and trees. Others of nearly equal height, occupying the side next to the ocean, are drifted by every passing wind, allowing no foothold to vegetation; and clouds of sand, seen at the Highland Light, are lifted from this tract by gales to the height of three or four hundred feet.

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THE HILLOCKS OR MOUND-FORMATIONS OF SAN DIEGO, CALIFORNIA.[1]

BY G. W. BARNES, M.D.

THE surface geology of many sections of the Pacific slope is characterized by innumerable hillocks or small mound-like formations, either sparsely distributed or occupying quite densely areas of considerable extent. These formations, variable in size

[1] Read before the San Diego Society of Natural History, April 5, 1879.